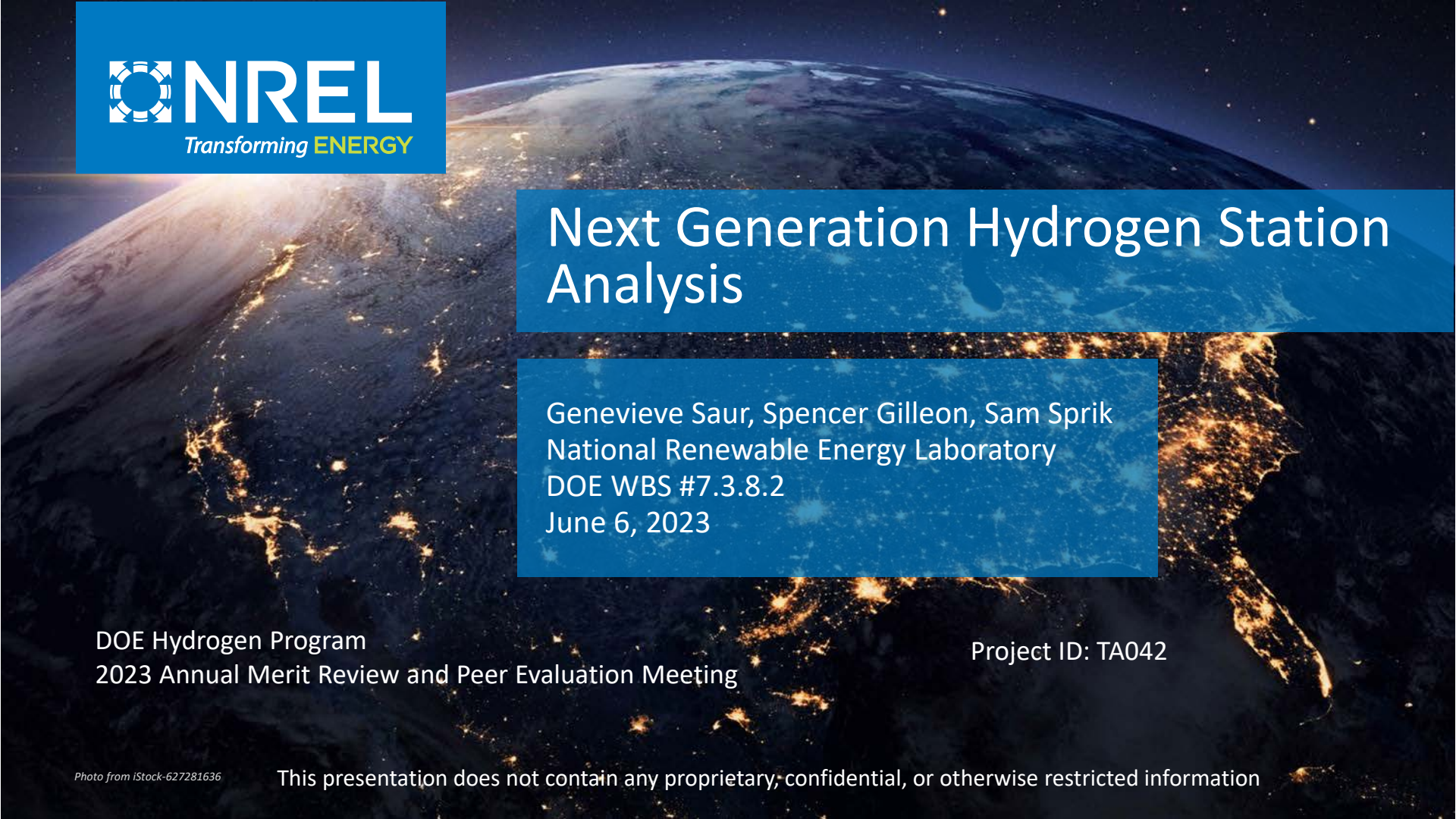


Next Generation Hydrogen Station Analysis

Genevieve Saur, Spencer Gilleon, Sam Sprik
National Renewable Energy Laboratory
DOE WBS #7.3.8.2
June 6, 2023

DOE Hydrogen Program
2023 Annual Merit Review and Peer Evaluation Meeting

Project ID: TA042

Photo from iStock-627281636

This presentation does not contain any proprietary, confidential, or otherwise restricted information

A Developing Market

- 59 retail stations open (55 last AMR)
  - 58 in CA, 1 in HI
  - As of April 2023
- At least 49 new stations planned
  - 43 CA, 5 Northeast, 1 OH
- Supporting over 15,722* FCEVs
  - 733* FCEVs sold in 2023 thru March

Photos: NREL

Project Goal

OBJECTIVE:

Independent analysis of advanced hydrogen and fuel cell technologies operating in real-world conditions for status, benchmarking, technology readiness, value proposition, and research needs.

IMPACT:

- Insight into needed R&D to improve performance and adoption
- Validation of technologies against technical targets
- Regular technology reporting without revealing proprietary information to align industry
- Status and trend of reliability, fuel economy, range, and driver behavior

Overview

Timeline and Budget

- Project Start Date: 10/2011
- FY22 DOE Funding: $200
- FY23 Planned DOE Funding: $150k
- Total DOE Funds Received to Date**: $2.35M

** Since the project started

La Canada, CA. Photo: Dennis Schroeder/NREL

Barriers

- Barriers and Targets
  - Lack of current hydrogen refueling infrastructure performance and availability data

Partners

- Partner organization – see Collaborations slide

Impact: Evaluating Existing Stations/Equipment

Objectives

- Support deployment of clean energy infrastructure
- Use existing stations as real-world guide for future innovations
- Identify issues for research
- Have results readily available (both public and private)

Irvine, CA. Photo: NREL

True Zero, Long Beach, CA. Photo: NREL

Impact

Reducing cost of H2 refueling infrastructure by:

- Quantifying how stations are used for build-out optimization
- Evaluating reliability of components and stations
- Reporting on H2 quality for different production methods
- Assessing the state-of-technology for evaluating development needs

** https://www.anl.gov/es/light-duty-electric-drive-vehicles-monthly-sales-updates*

Approach: NFCTEC Data/Analysis/Results Handling

Bundled data (operation and maintenance/safety) delivered to NREL quarterly

DDPs

Internal analysis completed quarterly

NREL's National Fuel Cell Technology Evaluation Center

Results

Confidential

Public

CDPs

Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months[1]

Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months[2]

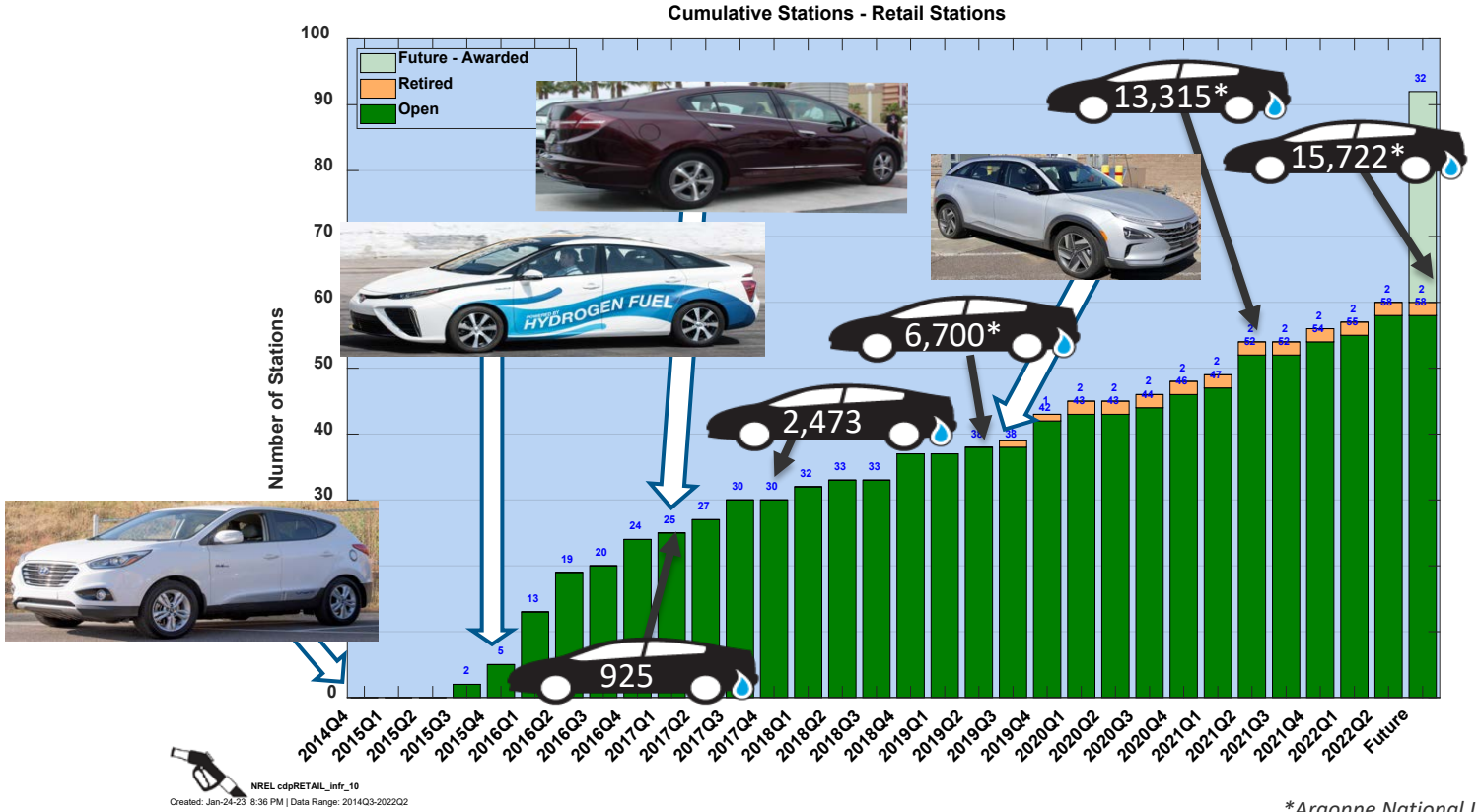
1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports

CDPs published with data through 2022Q2 (Spring/Summer 2023)

https://www.nrel.gov/hydrogen/hydrogen-infrastructure-analysis.html

Accomplishments and Progress:

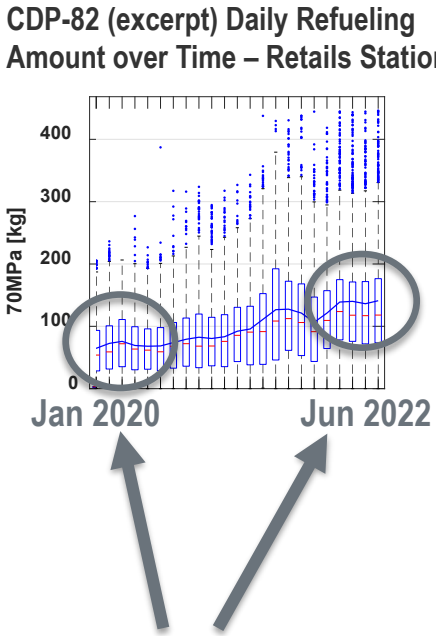
Cumulative Number of Retail Stations



*Argonne National Laboratory, 2023

Next challenge: Medium/heavy duty FC truck refueling

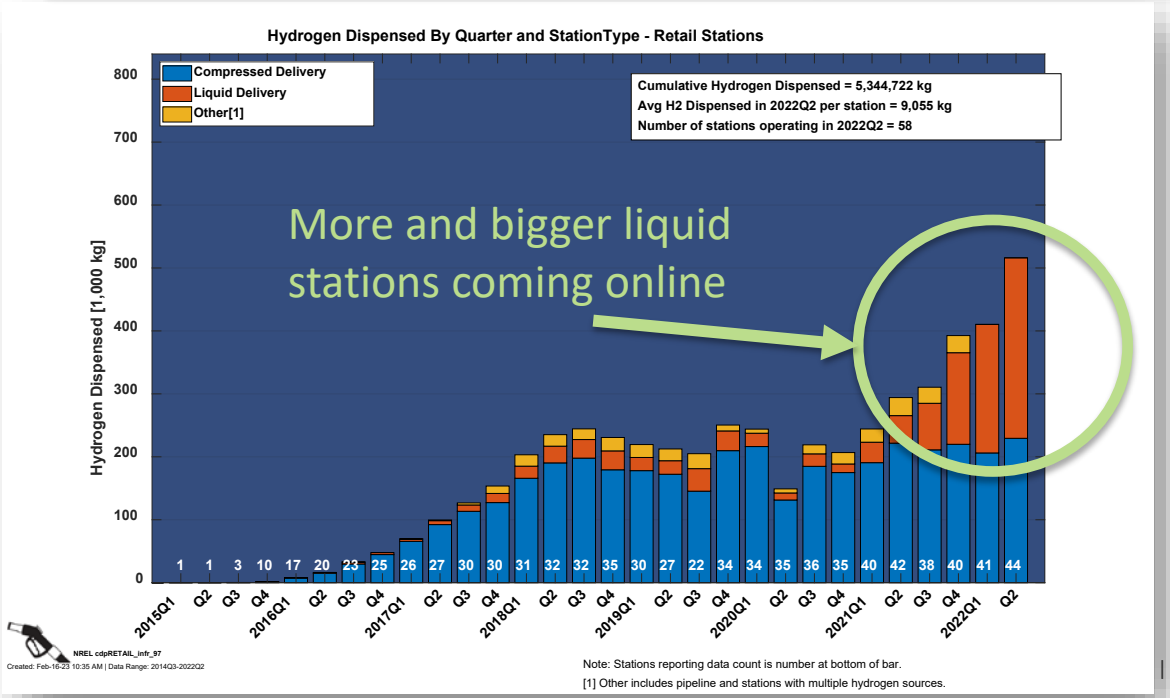
Accomplishments: Dispensed hydrogen increasing rapidly



Pandemic dip (Jan 2020) has steadily increased and surpassed previous totals (June 2022)

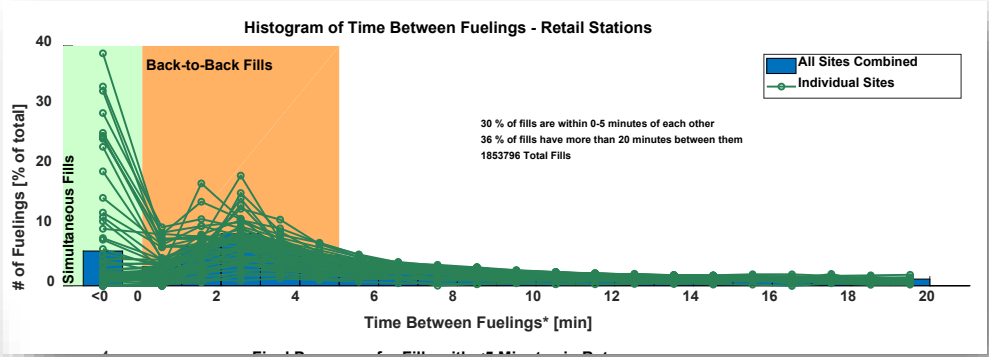
Data for stations reporting

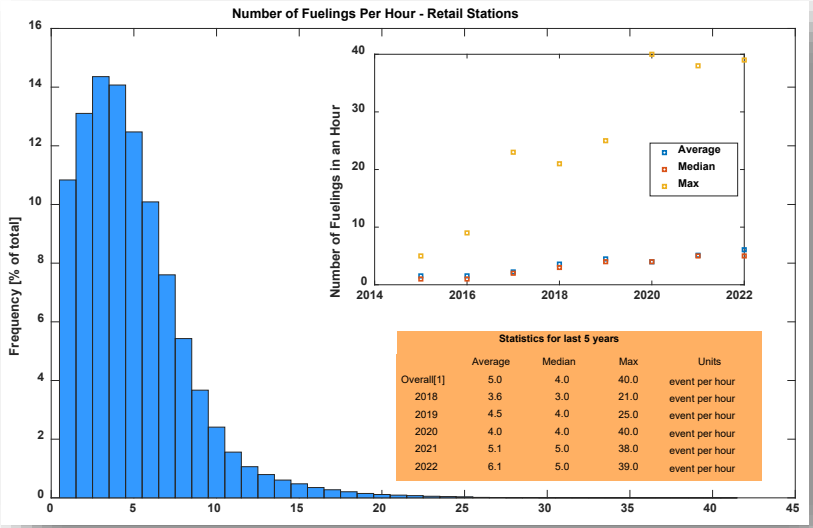
- Average daily amounts at stations now >100 kg H2/day
- Average dispensed per station in 2022 Q2 was 9,055 kg almost **doubled** in one year (5,767 kg in 2021 Q2)



Accomplishments: More fueling in shorter time

- 30% of all refueling events occur within 5 min or less of each other. That percent is growing!
- The average number of refueling events per hour is ~6 in 2022 (through Q2), 35% increase since 2020!



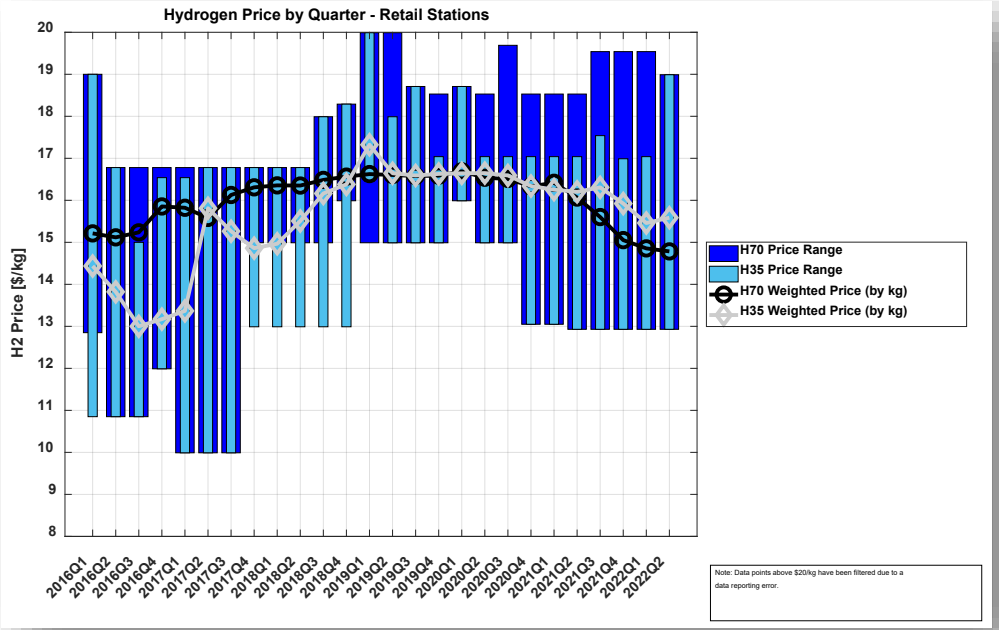


Washington, DC. Photo: Keith Wipke/NREL

Accomplishments: Cost of H2 is dropping!

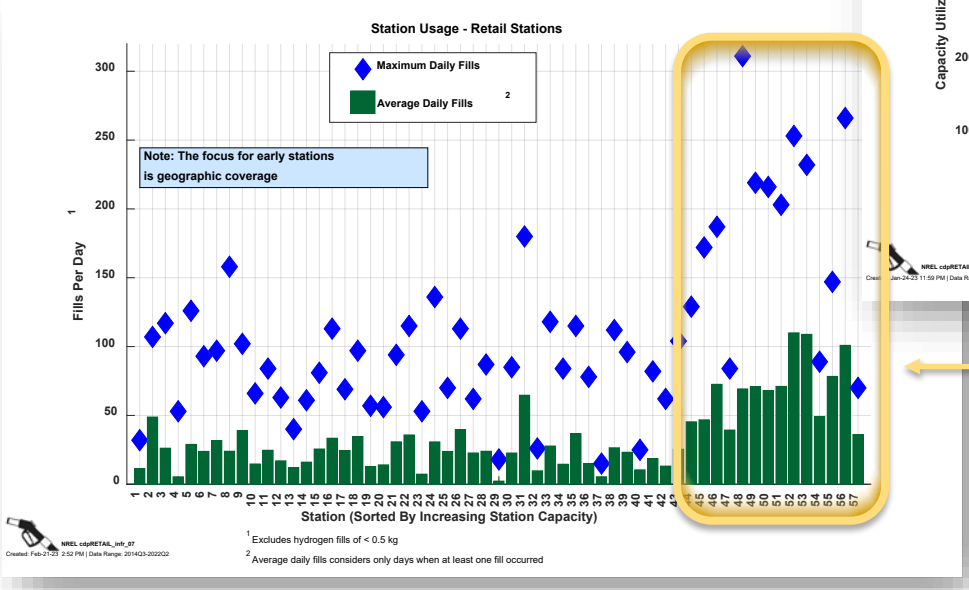
- The cost of retail hydrogen is beginning to drop as infrastructure is built and utilization increases
- H70 now <$15/kg weighted average

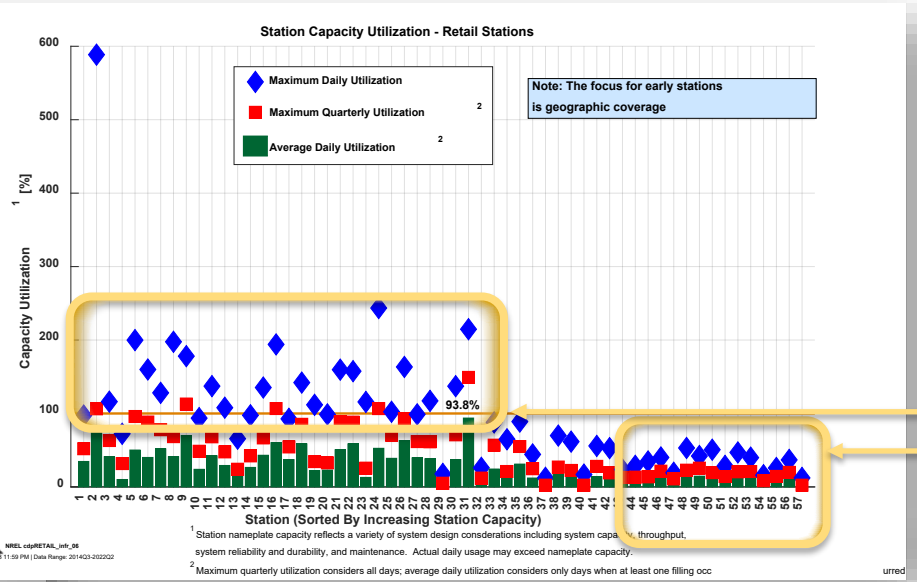
Hollywood, CA. Photo: Dennis Schroeder/NREL



Accomplishments: New stations meeting higher demand

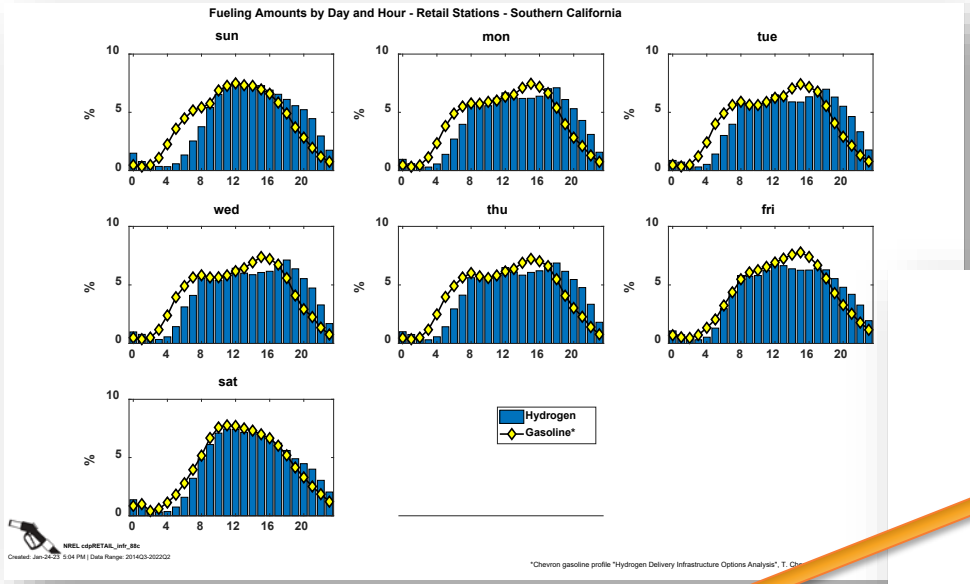
Higher capacity stations are coming online and are making more fills per day (~2x).



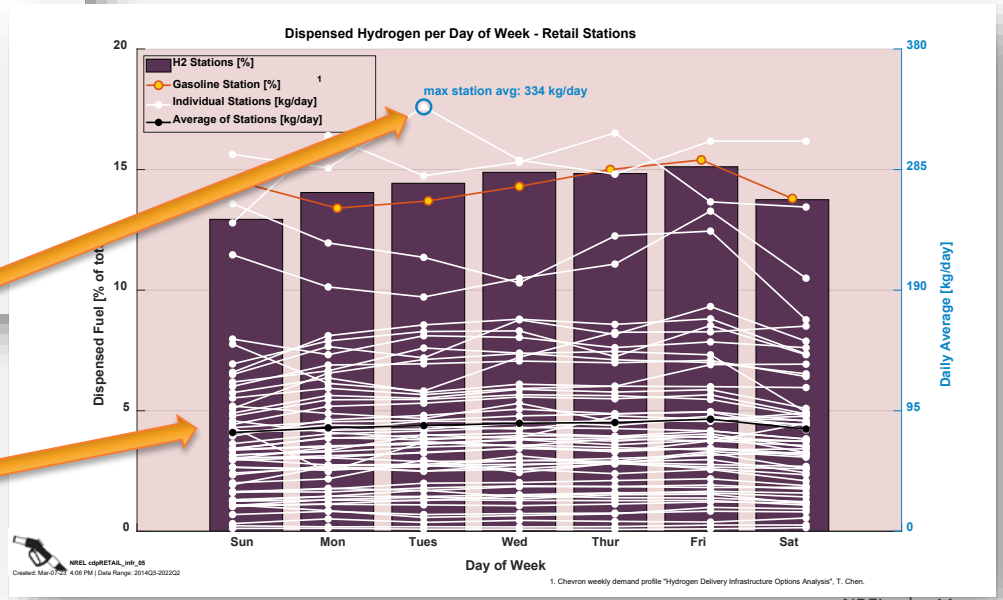


- Newer stations have lower capacity utilization due to higher capacity
- But they are making more fills per day!
- Older stations exceeding daily capacity utilization

Accomplishments: Daily profiles of stations

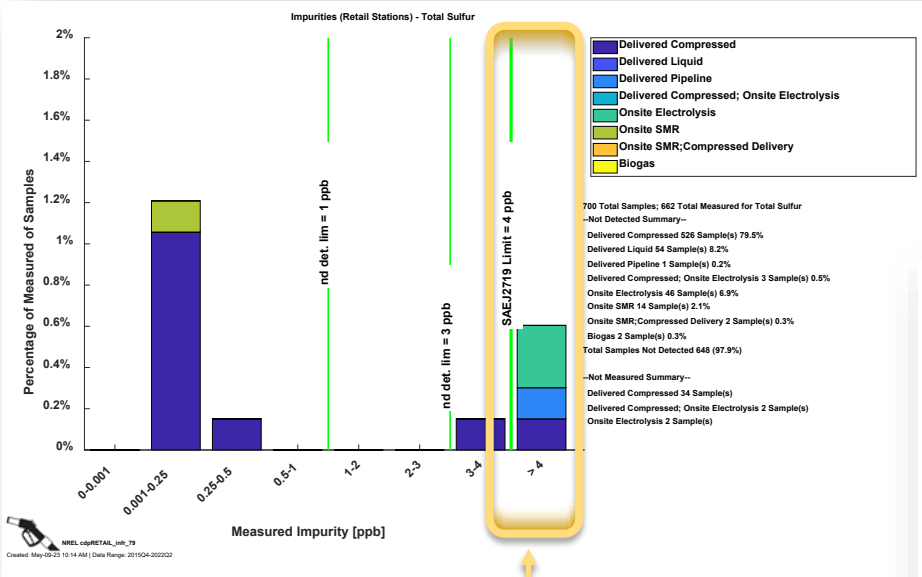


Published profiles provide understanding of how stations are being used.



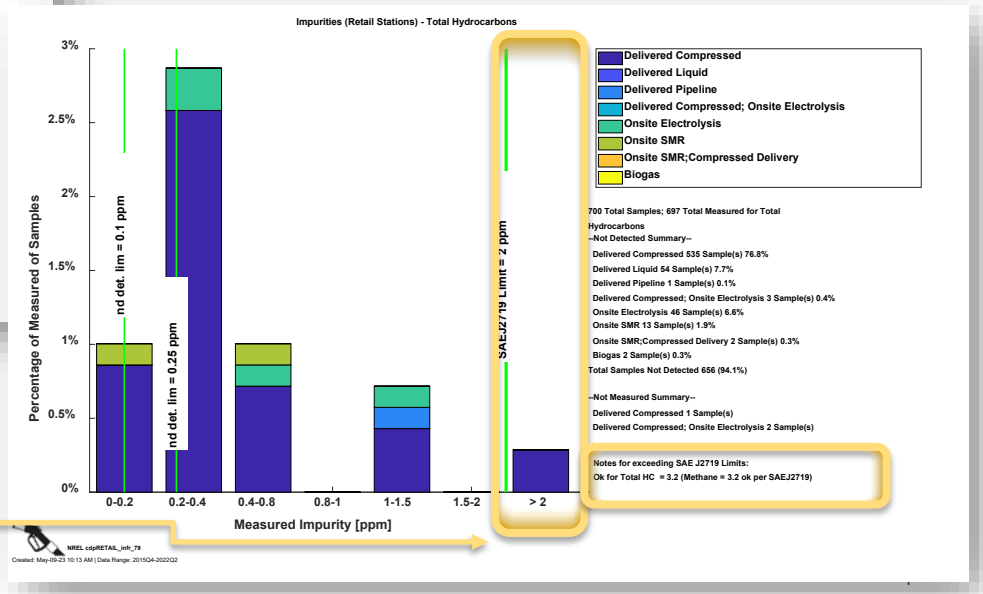
- Max station daily dispensed (kg/day) has doubled in one year!
- Average station daily dispensed (kg/day) has doubled in one year! Now almost 95 kg/day

Accomplishments: H2 quality monitoring



NREL publishes hydrogen quality data that can inform:

- In-line sensor needs
- Quality assessments of different pathways



- Sulfur can poison fuel cells
- Total hydrocarbons exceeded limits, but was ok per SAE J2719 criteria for methane

Accomplishment: Defining a **Hy**drogen **C**omponent **Re**liability **D**atabase (HyCReD)

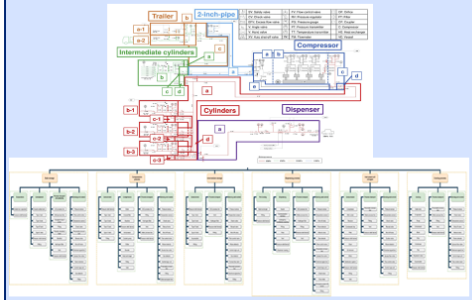
Evaluated existing H2 safety data collection tools

	Data Type	H2Tools	NREL CDPs	HIAD	CHS Failure Rate Data
Event and failure characterization	Initiating event (description)	✓	✓	✓	x
	Location within system	x	✓	O	x
	Failure mode	x	x	x	x
	Failure mechanism	x	x	x	x
	Failure root cause	✓	✓	✓	x
	Release size	x	O	✓	✓
	Incident severity	✓	✓	✓	✓
	Consequences	O	✓	✓	O
	System response (Mitigation)	x	x	x	O
	H2 accumulation	x	x	x	x
	H2 detection	x	x	x	O
Life/usage	Component life	x	x	x	x
	Operations	x	✓	x	O
	Maintenance	x	✓	x	O
	Site inventory	x	✓	x	O
Data scope	Public access to data	✓	x	✓	?
	Scope includes any H2 incident	✓	x	✓	✓
	Regular reporting	x	✓	x	✓
	Anonymous data presentation	✓	✓	✓	✓
	Data quality checks	x	✓	x	?
	Process documentation	x	x	O	x

Defined a set of 23 requirements for HyCReD

Characteristics	Static data	Failure event data	Maintenance event data
• Design for usability • Publicly available • Regular reporting • Anonymity • Quality assurance • Regular updating • Process documentation	• Component location • Operating condition • Component life • Number of like components	• Narrative event description • Failure mode • Failure mechanism • Root cause • Release location & size • Hydrogen accumulation • Detection • Isolation • Consequence • Severity	• Type of maintenance • Maintenance action performed • Active repair time • Manhours

Developed H2 fueling station system decomposition taxonomy



Defined 44 H2-specific component failure modes

Failure Mode	Definition
Abnormal output-high	Above normal output indicates potential failure(s)
Abnormal output-low	Below normal output indicates potential failure(s)
Bent/warped/damaged	Visible damage
Contamination	Component allows foreign material to contaminate product
Drift	Erroneous reading due to lack of calibration
Erratic output	Inconsistent output
External leak hydrogen	Hydrogen leak from within system to environment
External leak utility medium	Utility medium leak from the system to the environment
External rupture hydrogen	Complete loss of containment, hydrogen exhausts to the environment
External rupture utility medium	Complete loss of utility medium to the environment
Fail closed	Component stops working in the closed position
Fail open	Component stops working in the open position
Fail to close	Component does not close on demand
Fail to disconnect	Components meant to disconnect does not do so on demand
Fail to evaporate	Hydrogen remains in liquid form after passing through evaporator
Fail to operate	Component does not function on demand
Fail to stop	Component does not stop on demand
Freezing	Component is frozen and becomes inoperable/requires maintenance
Insufficient heat transfer	Target parameters for temperature are not met in a heat exchanger
Internal leak hydrogen	Hydrogen leak within system boundary (e.g. across a closed valve)
Internal leak utility medium	Utility medium leak within system boundary (e.g. across a closed valve)
Internal rupture hydrogen	Complete loss of containment, hydrogen stays within the system boundary
Internal rupture utility medium	Complete loss of containment, utility medium stays within the system boundary
Open circuit	Electrical circuit that is not complete
Overheating	Component is exposed to temperatures above design specifications
Overspeed	Component operates above desired/specified speed
Plugging	Buildup of material restricting flow
Restrict flow	Component is restricting flow when not intended to do so
Short circuit	Diversion of current
Spurious operation	Activation without specified demand (components normally idle)
Spurious stop	Stop without specified demand (components normally active)
Stuck connection	Component is stuck at point of contact (no/zla)
Underspeed	Component operates below desired/specified speed

Developing & validating HyCReD structure

- **Static data fields**

Event Number	Station/Facility Identification	Facility Type	Service/Usage	Nominal Working Pressure	H2 phases on site
25	A	Commercial, public	Heavy-duty	700 bar	Gas
26	B	Research, limited-access	Both heavy- and light-duty	350 bar	Gas

Event Number	Equipment Description	Subsystem	Functional Group	Component	Component Nominal Working Pressure	Component Population	P&ID Part Number
25		Bulk storage	Containment	Type III tank	250-300 bar	18	TK-103
26		Compression process	Compression	Compressor	400-680 bar	2	CO-E-49A

- **Failure event data fields**

Event Number	Time & Date of Failure	Failure Mode	Failure Severity	Failure Mechanism	Failure Root Cause Description	Hydrogen Release (Yes/No)	Release Size (Small/ Medium/La rge)	Ignition (Yes/No)
25	07/17/2021 08:32	External leakage-Process medium	Critical	Leakage		Yes	Medium	No
26	10/17/2021 15:33	Parameter deviation	Degraded	Overheating		No	Small	No

- **Maintenance event data fields**

Date & Time Repair Started	Date & Time Repair Completed	Date & Time Station Restarted	Action Performed	Maintenance Description
07/18/2021 09:55	07/28/2021 10:00	07/29/2021 09:30	Replacement	
10/17/2021 17:30	10/20/2021 13:30	10/20/2021 15:30	Repair	

NREL NATIONAL RENEWABLE ENERGY LABORATORY

- New initiative for maintenance and safety reporting supports component reliability and qualitative risk assessment. See SCS001.

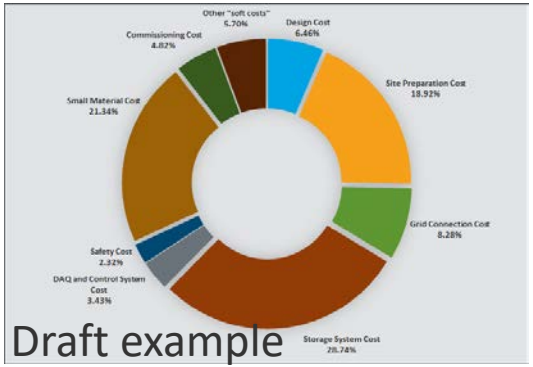
- Al-Douri, A.; West, M. A. & Groth, K. M. "A Foundational Framework for Reliability Data Collection for Hydrogen Systems." AIChE 2022 Spring Meeting and the 18th Global Congress on Process Safety, 2022
- Katrina M. Groth, Ahmad Al-Douri, Madison West, Kevin Hartmann, Genevieve Saur, William Buttner. "Design and Requirements of a Hydrogen Component Reliability Database (HyCReD)," Submitted to IJHE in March 2023.

Approach and Future: Related Project Electrolyzer Installation Costs

Like CDP projects: We will collect, analyze, aggregate and present the **costs** associated with the **installation of electrolyzers** while not revealing which data pertains to which specific company.

Progress:

- Template developed to collect information
  - Level of detail for each category can be a lump sum or detailed breakdown (preferred)
- Contacted companies
- Exercised with NREL installation



NREL
Transforming ENERGY

Electrolyzer Installation Costs

Categories	Parameter	Site Specific Info	Comments
	Site Name		
	City, State		
	Point of Contact		
	Date		
	Commission Date		

	Reviewed Detailed Tab	Cost Estimate from Detailed Tab	Method to Determine Cost	Lump sum Cost Estimate	Comments	Phase Completion Timeline (
Land Cost	Yes	$0.00	Detailed Cost			0
Design Cost	Yes	$0.00	Detailed Cost			0
Site Preparation Cost	Yes	$0.00	Lump sum Cost			0
Grid Connection Cost	Yes	$0.00	Detailed Cost			0
Storage System Cost	Yes	$0.00	Detailed Cost			0
Data Acquisition System and Control System	Yes	$0.00	Detailed Cost			0
Safety	Yes	$0.00	Detailed Cost			0
Financial Cost	Yes	$0.00	Detailed Cost			0
Small Material Cost	Yes	$0.00	Detailed Cost			0
Commissioning Cost	Yes	$0.00	Detailed Cost			0
Other "soft costs"	Yes	$0.00	Lump sum Cost			0

Cost from Each Estimate Type	$0.00		$0.00
Electrolyzer Installation Cost			$0.00

Optional: Please enter the cost overrun (if any)	Planned/Estimated Budget ($)	Actual Expense (Basically Installatio ($)
		$0.00

Revision History | Installation Cost Summary | System Information | Land Cost | Design Cost | S +

Collaborations

Data Requirements > Data Reporting > Analysis Results > Feedback

STATION FUNDERS

California Energy Commission
California Air Resources Board
SCAQMD

STATION PROVIDERS

Air Liquide
Air Products
California State University Los Angeles
Equilon
First Element Fuel
H2 Frontier
ITM Power
Iwatani
Linde
Messer
Proton OnSite/NEL
Shell
Stratos Fuel

ORGANIZATIONS

California Fuel Cell Partnership
IPHE and HySUT
Gas Technology Institute
CA - CDFA Division of Measurement Standards
University of Maryland Center For Risk and Reliability[1]

[1] New collaboration along with NREL's Hydrogen Safety Research & Development Group supporting component reliability, qualitative risk assessment, and station prognostic health maintenance. See SCS001.

Accomplishments and Progress:
Response to Previous Year Reviewers' Comments

Project was not reviewed in FY22, comments taken from FY21

- "The project could benefit from shifting from light-duty (LD) vehicles and an LD infrastructure focus to heavy-duty (HD) vehicles and an HD infrastructure focus"
  - *Agreed. We expect to shift away from the emphasis on LD stations, however we are limited based on data reporting requirements of the station funders. We revisit the emphasis and requirements when we can, eg California solicitations.*
- "More work on component reliability and maintenance trends will be very helpful. It is good that this was proposed by the team."
  - *Initial work on a maintenance reporting taxonomy has been done in conjunction with SCS001 and University of Maryland. We have also received funding to develop this as an online tool, HyCReD, for near real-time reporting capability. We will use this to answer questions around component reliability, quantitative risk assessment, prognostic maintenance that will guide R&D and reduce maintenance costs (H2 Energy Earthshot need) and increase reliability.*
- "The team should consider exploring how this can be accelerated to align with the pace of technology development and industry focus on rapid acceleration of infrastructure rollout."
  - *Agreed, there are limitations in how this project is structured, but we are pursuing opportunities through this project and others to utilize the National Fuel Cell Evaluation Center capability for data security and independent analysis to provide better insight into technology status and critical barriers in deployment.*

Remaining Challenges and Barriers

- A delay in processing of maintenance data has postponed CDPs that utilize that data and metrics
  - I expect a staggered release of those CDPs in Summer 2023, outside of normal schedule.
- High quality data is always a need for the projects
  - Changing requirements from CA solicitations
  - Identified taxonomy for HyCReD will require expanded efforts

Proposed Future Work

Any proposed future work is subject to change based on funding levels

- We are pursuing development of an online maintenance reporting tool, HyCReD, which will address timeliness and quality of data.
  - Expand data analysis around reliability and safety
- Pursue other station data providers, especially around MD/HD trucking infrastructure
- Investigating streamlining data collection in other online tools to better align with the expanding industry.
- Provide snapshots of data that only include latest (5) years.

Summary

- Average dispensing totals doubled in one year, we are seeing the effects of the rapid expansion away from very early market.
- Larger capacity stations are coming online and are experiencing double the refueling events of early stations
- Older stations are seeing higher capacity utilization and even exceeding 100% on some days
- One third of refueling events in 2022 occurred within 5 min of each other, the infrastructure is getting stress-tested
- Work in progress to address reliability and electrolyzer costs

Thank You

www.nrel.gov

NREL/PR-5400-86009

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Technical Backup and Additional Information

Technology Transfer Activities

- No activities

Publications and Presentations

- Saur, Genevieve, Spencer Gilleon, and Sam Sprik. Next Generation Hydrogen Station Composite Data Products: Retail Stations; Summer 2021: Data Through Quarter 2 of 2021, 2022.
- Saur, Genevieve, and Spencer Gilleon. Next Generation Hydrogen Station Analysis, 2022, DOE Annual Merit Review 2022.
- Hartmann, Kevin, A. Al-Douri, J. Thorson, W. Buttner, G. Saur, K. Groth, Component Failure Taxonomy and Leak Rate Quantification for Hydrogen Systems, Center for Hydrogen Safety Americas Conference on Hydrogen Safety (September 20 - 22, 2022), Long Beach CA
- Al-Douri, A., West, M. A., Groth, K., Hartmann, K., Saur, G., Buttner, W., Design and Requirements of a Hydrogen Component Reliability Database (HyCReD), AIChE Spring Meeting and Global Congress on Process Safety, 2023.